Pest Management Grants Final Report

Project Title: Quantification and Modeling of the Effects of Predation on Aphid Populations in Prune: Developing a Forecasting Model for in Season Management

Agreement number: 00-0213S

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Date: February 28, 2002

Prepared for the California Department of Pesticide Regulation

Disclaimer

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Acknowledgements

We would like to acknowledge the work of the principle investigator, Nicholas J. Mills, Associate Professor, Insect Biology, at the University of California, Berkeley, and doctoral candidate in Insect Biology, Daniel R. Latham. We are grateful to growers for their cooperation: Dan Bozzo, John Heier, and Brad Johnson.

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Executive Summary

The mealy plum aphid, *Hyalopterus pruni,* is the most significant barrier to full adoption of reduced risk management in prunes. This aphid develops large populations on the undersides of leaves in the spring. Aphids sap tree vigor, slow growth, reduce the photosynthetic capacity of the trees, reduce fruit quality, and cause fruit splitting. Conventional control of aphids with organophosphates poses a risk to human and wildlife health, pollutes streams and groundwater, and disrupts natural biological control. Thus, development of effective reduced risk practices is essential. The overall goal of this project is to develop a forecasting model that will assist decision-makers to assess the threshold for within season treatments against the mealy plum aphid in prune. Parameters for this model have been estimated from field and laboratory data. We have measured aphid and predator population densities over three years. The aphid population growth parameters were determined in prune orchards by excluding predators from small sleeve cages ($r_i = 0.1421$) and in the laboratory on potted prune trees at 18 ºC ($r_m = 0.2893$). The proportion of time predators spend feeding was measured by direct observation in prune orchards. *Chrysopa nigricornis* and *Harmonia axyridis* were the most abundant predators (36% and 30%, respectively), while *Leucopis sp.* had the greatest number of feeding events (28%). The time individual predators take to consume a single prey item was measured in the laboratory. We have combined these estimates of predation rates of each predator species with 96-98 field data on aphid and predator densities to quantify the impact of predation on the mealy plum aphid. Thus, we have calculated the *estimated predation potential* of the predator guild and the *required predation potential* needed to account for the observed change in aphid population density for a known rate of aphid increase. The estimated predation potentials of individual species were extremely low in comparison to the required predation potentials. One the whole, at the growth rate examined, the abundance of the predator guild and the feeding potentials of the individual species were not sufficient to influence the observed changes in aphid population size in the orchards monitored. However, *Chrysopa nigricornis* and *Harmonia axyridis* larvae are consistently the most effective predators across orchards and years.

Report

A. **Introduction**

***Objective One*:** Determine aphid population rates of increase in four orchards in the Sacramento valley.

As a first step toward developing a forecasting model, we proposed to determine population growth rates of the mealy plum aphid (MPA). Population growth rate, a parameter summarizing the age specific mortality and fecundity of a population, is the most important factor governing the potential impact of pests, such as the MPA, that have a relatively short generation time. The population growth rate of aphid populations is influenced primarily by temperature and nutritional status of the plant. Through the 2001 growing season we estimated both the instantaneous rate of increase and the intrinsic rate of increase of mealy plum aphid on prunes.

Task: We estimated the instantaneous rate of increase ($r_i = \ln(N_t/N_o)/t$) from the change in number of aphids (initial N_o and final N_t) in small sleeve cages on prune tree branches over a fixed period of time ($t = 7$ days) and made successive estimates through the season in three prune orchards.

Similarly, we estimated the intrinsic rate of increase (r_m) using $r_m = 0.74\ln(Fd/D)$ where fecundity (Fd) is the number of offspring produced per adult female aphid over a period equal to the development time (D) of the aphid (roughly ten to 14 days) by monitoring developmental times and fecundity of small cohorts of aphids in clip cages on potted prune trees under constant temperatures.

***Objective Two*:** Quantify predator impact on aphid populations.

Quantification of predator impact would allow forecasting based on predator as well as aphid abundance when making management decisions about the need for in-season treatments. The forecasting model would include a component that quantifies the impact of predation on aphid populations, based on spring observations of predator abundance.

Task: The proportion of time each predator species spends feeding was measured by direct observation in prune orchards. The time individual predators take to consume single prey items was measured in the laboratory. These data have been combined with data on aphid and predator densities and known MPA reproduction rates to quantify the impact of predation on the mealy plum aphid. This simple approach compares two quantities for each sample date: the ***required predation potential*** to cause the observed change in aphid population density for a determined rate of aphid increase, and the ***estimated predation potential***.

***Objective Three*:** Develop a forecasting model that will predict the threshold for in season applications based on observed aphid or predator abundance.

We proposed to develop an easy to use forecasting model for use by farm advisors, growers and PCAs to predict threshold levels for in season management treatments. The model would integrate aphid population growth rates, the roles of natural enemies, and reduced risk management practices. Parameters for the model have been estimated from data collected on aphid and predator population growth rates and predator feeding rates.

Task: In order to develop a simple model that effectively captures the complexity of the system, we proposed to develop a simulation model that will test the relative importance of the many parameters in this complex system. The simulation model takes the form of a multitrophic, age structured, metabolic pool model. The multitrophic model comprises linked sub-models of each trophic level (tree, aphid, predator). Populations at each trophic level are driven by resource acquisition, resource allocation, growth and aging, and physiological time. Developmental and reproductive rates that change through the season with each generation are applied.

B. **Materials and Methods**

Objective One

Successive measurements of the instantaneous rate of increase of mealy plum aphid colonies have been made at regular intervals over the season in three prune orchards. Young aphid colonies are identified (20-100 individuals) on growing shoots and all predators were carefully removed. Branches were bagged 7-10 days between each measurement. Temperatures were monitored continuously using Hobo temperature data loggers installed in each orchard.

Initial attempts to sleeve cage and monitor the growth rate of aphid populations early in the season were less successful because we pruned leaves from the shoot tips in an effort to standardize leaf number and leaf surface area between sleeves. This weakened the prune shoots and limited the space available for the developing colonies such that they showed positive growth rates for the first week only, after which overcrowding led to negative growth rates. Larger shoots with more leaves were used subsequently. For each observation period, half of the sleeves in each orchard contained newly established aphid colonies (<100 aphids), and the other half contained older colonies that had been sleeved for one to several weeks already. In this way, we were able to determine the growth rates of colonies as they aged at different periods through the season.

Development times and offspring production were monitored in twenty clip cages on potted prune trees, under controlled light (16hL/8hD) at one of five constant temperatures (14, 18, 22, 26, 30 ºC). To measure developmental time, small cohorts of neonate nymphs produced during a 24 hour period by 5 adult female aphids were followed through each instar molt until reaching first reproduction. Fecundity was measured by placing single fourth instar nymphs in clip cages. Offspring production of resulting adults was monitored daily until adult death.

Objective Two

Direct observations of the feeding potential of indigenous predators were carried out in two prune orchards in the Sacramento Valley. A set of 30 trees in each orchard were selected for variation in abundance of mealy plum aphids and point observations of the activity of individual predators were made for a period of 10 minutes on each tree. Predators were identified to species and instar and their activity was classified as either feeding on aphids, cannibalism, searching, resting or other. Three rounds of observations were made per day to cover any variation in activity pattern through the day. In addition, individual predators and mealy plum aphids were collected from the orchards to determine the time taken to feed on an aphid under controlled conditions (20°C, 16h D, 70% RH). Predators were kept at 12°C overnight, presented with a single aphid in a small petri-dish with filter paper liner, and observed continuously to record duration of feeding in relation to the fresh weight of predator and prey.

The *required predation potential* was calculated by an iterative procedure of simulation, with step lengths of one day, starting from the observed aphid population density at the beginning of the sample interval and calculating a projected population trend to the next sample date. *Estimated predation potential* of each predator species was determined from the mean proportion of time that an average predator spends feeding during the day in relation to the time taken to fully consume a single prey item in the lab. Estimated predation potential is then related to aphid abundance on a tree by regression analysis.

Objective Three

Input parameters for the model are being estimated from data on aphid and predator abundance, predator feeding rates, and from developmental and reproductive rates. Estimating these parameters from field data is the first step toward model development. These efforts are described under Objectives 1 and 2 of this report. Compiling the model and testing the parameters is largely scheduled for the second project year. Weather data is being collected from CIMIS to be used as a driving variable for the simulations.

C. **Results**

Objective one

a. Results: Changes in the instantaneous rate of increase in two orchards in the middle part of the season follow each other very closely (Fig. 1). This is striking because, although both orchards are managed organically, tree age, ground cover management, nitrogen and irrigation regimes differed between orchards. The average growth rate across all orchards is $r_i = 0.1421$. Fig. 1 also shows the similarity of temperature fluctuation in the two orchards, and this suggests that temperature is the most important determinant of aphid growth rates during this part of the season.

Developmental time at 18 °C was determined by measuring the length of each nymphal instar and then summing the instar developmental times. Determination of

MPA developmental time at 18 °C is complete (Fig. 2). Average developmental time at this temperature is 10.45 days. The number of nymphs produced per adult per day is greatest at the intermediate temperature (22 °C), and decreases for all temperatures as adult age increases (Fig. 3). These quantities were used to calculate MPA fecundity (Fd = 15.44).

We have estimated the parameter the intrinsic rate of increase (r_m), calculated by $r_m = 0.74 \ln(Fd/D)$, where Fd is the number of offspring produced per adult female aphid over a period equal to the development time (D) of the aphid. As Fd = 15.44 and D = 10.45, then $r_m = 0.2893$. The intrinsic rate of increase measured at 18ºC is about twice the instantaneous rates of increase measured in the field. The field measurements of instantaneous rates of increase are an average of sleeved populations over a range of ages and stages of colony development. The maximum instantaneous rate of increase measured in one orchard, for example, was $r_i = 0.3560$. Thus, the value of r_m we estimated falls between the average and maximum values of r_i observed in the field. As we develop the forecasting model, we will use population growth parameters in this range, in order to examine the effects of predation under a variety of scenarios.

b. Problems: Our initial proposal to monitor instantaneous rates of increase from three sleeve cages on each of 15 trees in each of four orchards proved to be impractical and thus monitoring was reduced to twenty-five sleeves per orchard in each of three orchards. We were unable to find a fourth orchard in the same region with aphids that would not be sprayed out, and the number of sleeve cages in each orchard was limited by the availability of new young aphid colonies. However, the reduced level of monitoring was more practical and provided the data needed.

Monitoring the intrinsic rate of increase of the aphid populations in clip cages in the prune orchards was not successful as daily monitoring of the clip cages proved to be necessary to accurately estimate development times and fecundity. As a result this component of the project was changed. Instead, we monitored aphids brought back from the orchards, establishing them in clip cages on potted prune trees in the insectary. This had the advantage that a greater range of temperatures could be examined than in the field, enabling the estimation of a developmental threshold.

We were able to calculate r_m at 18 °C only. Developmental time could not be determined at other temperatures because no aphid nymphs survived to adulthood on potted trees under laboratory conditions. This is likely the result of trees that did not have sufficiently developed root systems. This experiment is currently being repeated.

Objective two

a. Results: The relative abundance of the larval stages of the major predator species varied (Fig. 4), with *Chrysopa nigricornis* and *Harmonia axyridis* the most abundant and *Aphidoletes aphidimyza* and *Chrysoperla carnea* the least abundant. Activity estimates indicate that, independent of abundance, the relative frequency of feeding also varied between predator species (Fig. 4), with the dipteran predators (*A. aphidimyza* and *Leucopis* sp.) and *C. nigricornis* spending almost twice as much time feeding as the coccinellid predators (*H. axyridis* and *Hippodamia convergens*) and *C. carnea*.

To quantify predation, the field observations of mean percentage of time spent feeding must be converted to biomass of aphids eaten per predator per day using a relationship between mean duration of feeding on a single prey item and predator-prey size ratio. The latter relationships were determined for the main predator species, with the exclusion of *A. aphidimyza,* which would not feed successfully on aphids in the lab. The resulting feeding time relationships for the other predators all provided consistent results (Fig. 5). The coccinellids and chrysopids typically spend a little less than 10 minutes consuming an individual aphid, whereas it takes more than an hour for *Leucopis* sp. to consume an aphid.

We have combined these estimates of predation rates of each predator species with 96-98 field data on aphid and predator densities to quantify the impact of predation on the mealy plum aphid. Thus, we have calculated the *estimated predation potential* of the predator guild and the *required predation potential* needed to account for the observed change in aphid population density for a known rate of aphid increase, ri = 0.1421, and have compared these quantities.

The *required predation potential* and *estimated predation potential* are shown in a series of charts (Fig. 6). The estimated predation potentials of individual species were extremely low in comparison to the required predation potentials. Thus, only the estimated predation potential for the entire guild is shown. The required predation potentials indicate the level of predation required to account for the observed changes in aphid densities. When the estimated predation potential is equal to the required predation potential, the activity of the predator guild is sufficient to account for observed changes in aphid density. However, this situation rarely occurred. On the whole, at the growth rate examined, the estimated potential of the predator guild falls below the predation rate that is required to influence the changes in aphid populations. Comparisons of predator species are shown in Fig. 7. *Chrysopa nigricornis* and *Harmonia axyridis* larvae are consistently the most effective predators across orchards and years.

b. Problems: No problems or changes.

Objective three

a. Results: This objective was not carried out due to the reduction of project length from 2 years to 1 year.

b. Problems: None

D. **Discussion:**

The average rates of aphid population increase in sleeve cages remained relatively constant over the middle part of the season. Also, rates of increase between orchards were similar suggesting the factors that most influence aphid growth rates do not vary much between orchards. These field measurements are an average of sleeved populations over a range of ages and stages of colony development. The maximum rate of increase measured in one orchard, for example, was r_i = 0.3560. The value of r_m, measured in the laboratory, falls between the average and maximum values of r_i observed in the field. As we develop the forecasting model, we will use population growth parameters in this range, in order to examine the effects of predation under a variety of scenarios.

The proportion of time predators spend feeding was measured by direct observation in prune orchards. *Chrysopa nigricornis* and *Harmonia axyridis* were the most abundant predators (36% and 30%, respectively), while *Leucopis sp.* had the greatest number of feeding events (28%). The time individual predators take to consume a single prey item was measured in the laboratory. We have combined these estimates of predation rates of each predator species with 96-98 field data on aphid and predator densities to quantify the impact of predation on the mealy plum aphid. *Chrysopa nigricornis* and *Harmonia axyridis* larvae are consistently the most effective predators across orchards and years. However, the estimated predation potentials of individual species were extremely low in comparison to the predation potentials required to influence aphid abundance. One the whole, at the growth rate examined, the abundance of the predator guild and the feeding potentials of the individual species were not sufficient to influence the observed changes in aphid population size in the orchards monitored. Research into the establishment and effectiveness of introduced wasp parasitoids may, therefore, prove useful.

1) Proposal Title

Quantification and Modeling of the Effects of Predation on Aphid Populations in Prune: Developing a Forecasting Model for in Season Management

Project Summary Form

2) Principal Investigator

Nicholas J. Mills, Associate Professor

3) Alternative Practices

The mealy plum aphid, *Hyalopterus pruni,* represents the most significant barrier to full adoption of reduced risk management in prunes. We proposed to develop a forecasting model to allow growers to predict the frequency and timing of in season management practices, such as oil application, given the rate of increase of aphid populations and the potential of indigenous predators and introduced parasitoids to reduce population size.

4) Summary of Project Successes

We have determined the instantaneous rates of increase of mealy plum aphid in three prune orchards. Predation rates for the six most important predator species have been quantified from field observations. Estimated predation potentials of the predator guild have been calculated and have been found to be insufficient to be able to influence aphid populations in prune orchards.

5) Number of Participating Growers	NA
6) Total Acreage in Project	NA
7) Project Acreage Under Reduced Risk	NA
8) Total Acres of Project Crop	NA
9) Non-Project Reduced Risk Acres	NA
10) Number of Participating PCAs	NA
12) Number of Field Days	
13) Attendance at Field Days	NA
14) Number of Workshops & Meetings	NA
15) Workshop Attendance	NA
16) Number of Newsletters	NA
17) Number of Articles	NA
18) Number of Presentations	NA

11) Cost Assessment

NA

19) Other Outreach Activities NA

FOR OFFICIAL USE ONLY

Contract Number ____________ Project ID ____________

DPR ID# ____________ Contract Manager ____________

25th May 2001

APPENDICES

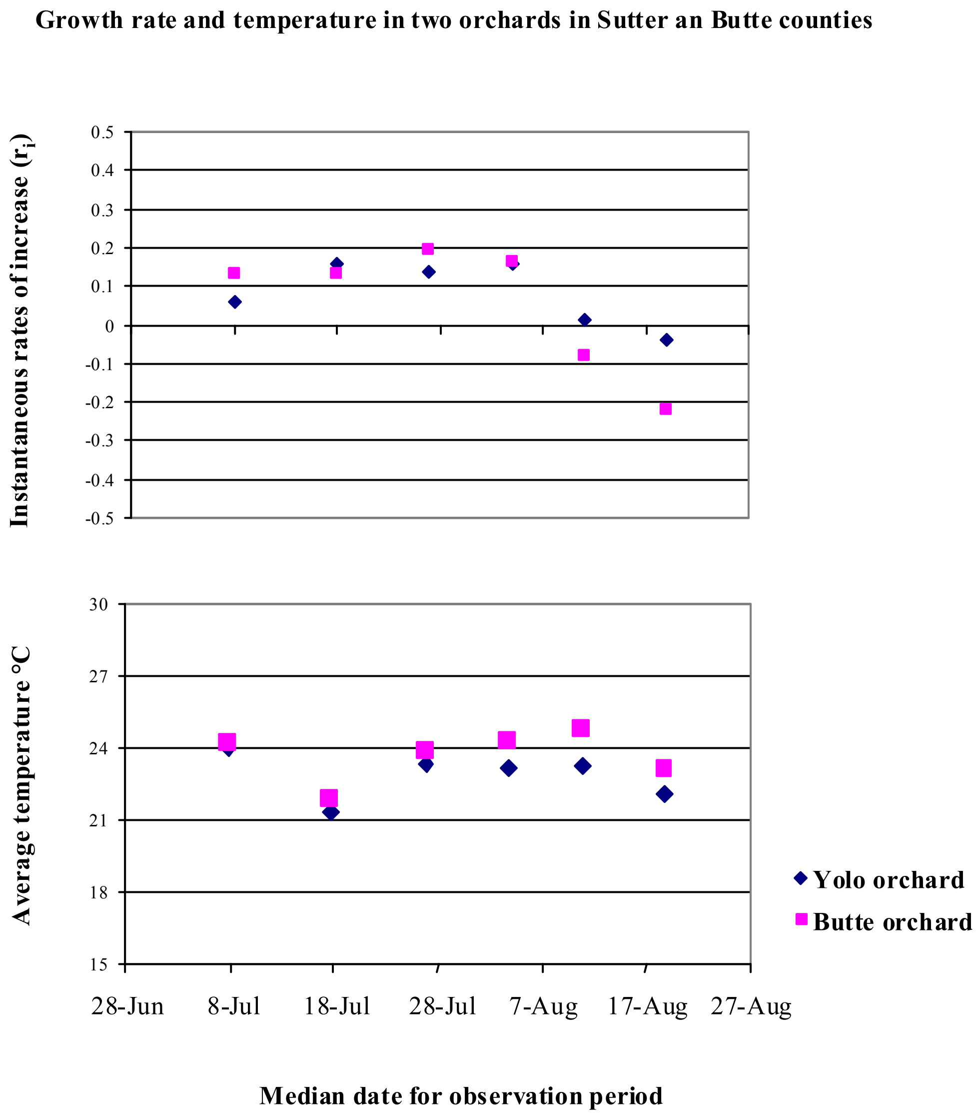


Fig 1. Changes in instantaneous rates of increase of MPA and temperatures in two prune orchards in Sutter and Butte counties.

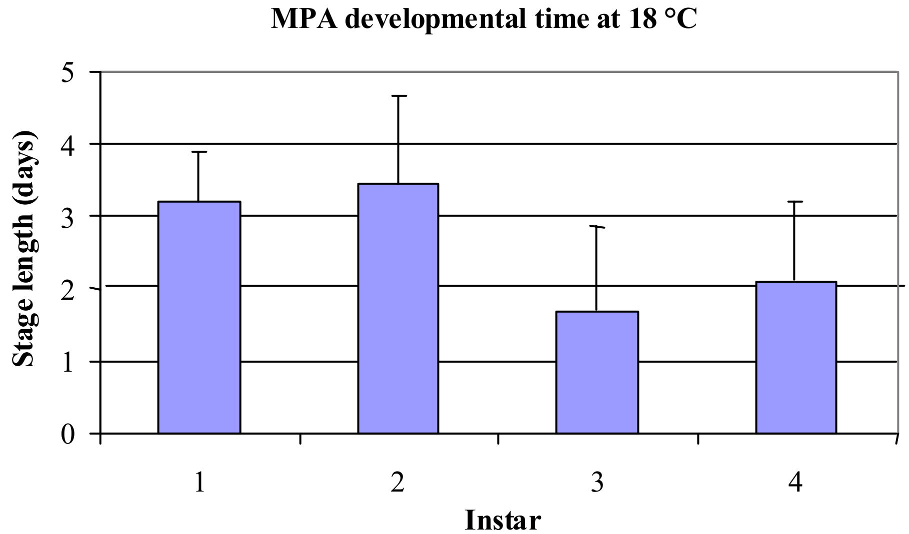


Fig. 2. Developmental times for each instar of MPA measured in clip cages on potted prune trees. Total developmental time is 10.45 days. Bars are standard deviation.

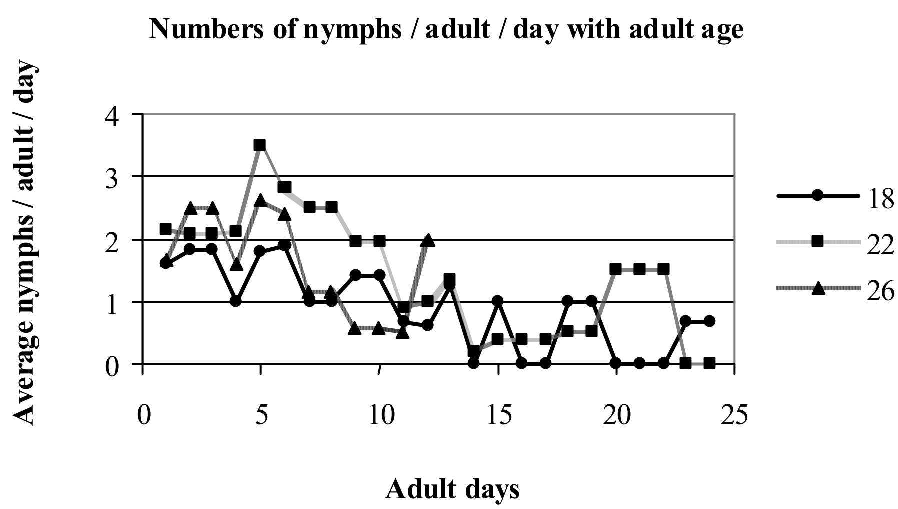
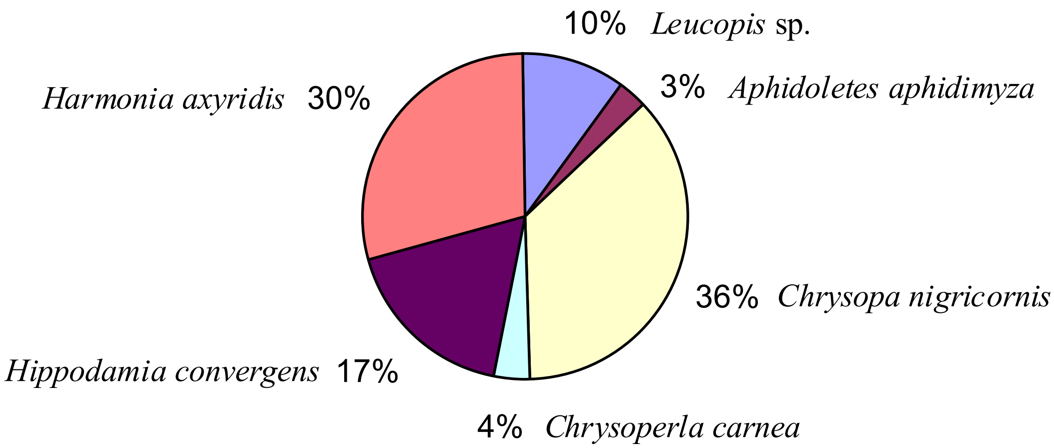


Fig. 3. Nymph production per adult MPA per day in relation to age measured in clip cages on potted prune trees at three temperatures (18, 22, 26 ° C).

a. Relative abundance of predator larvae on MPA



b. Relative frequency of feeding by predator larvae on MPA

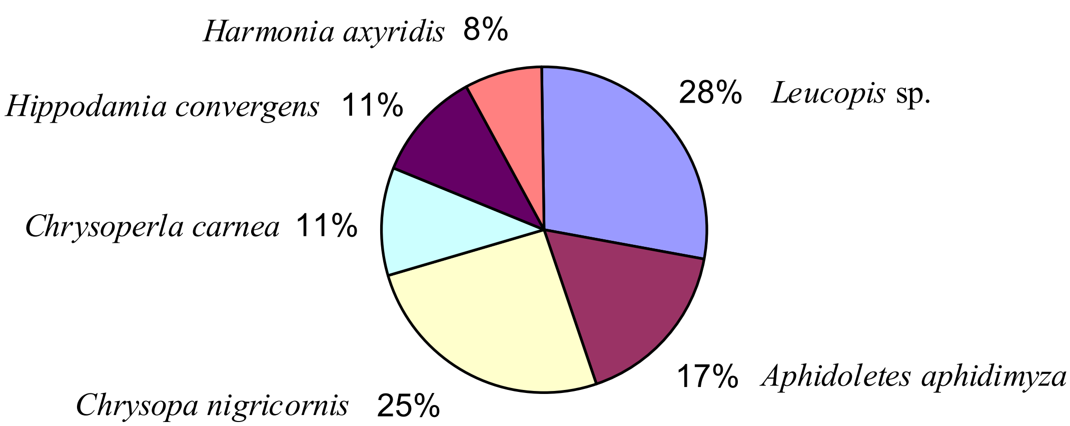


Fig. 4. The relative abundance of (a) and the relative frequency of feeding by (b) the larval stages of the main predators of the mealy plum aphid in prune orchards.

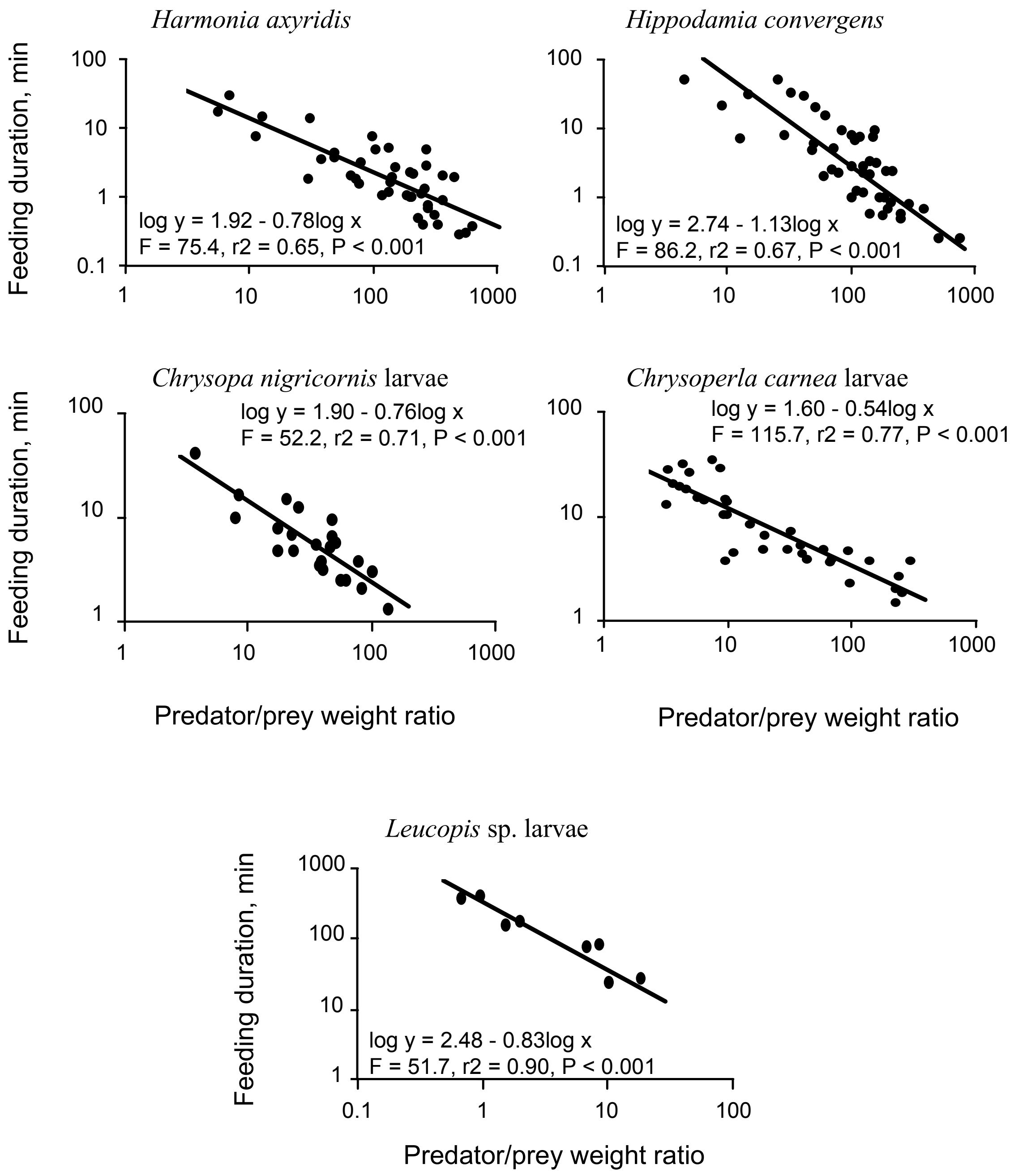
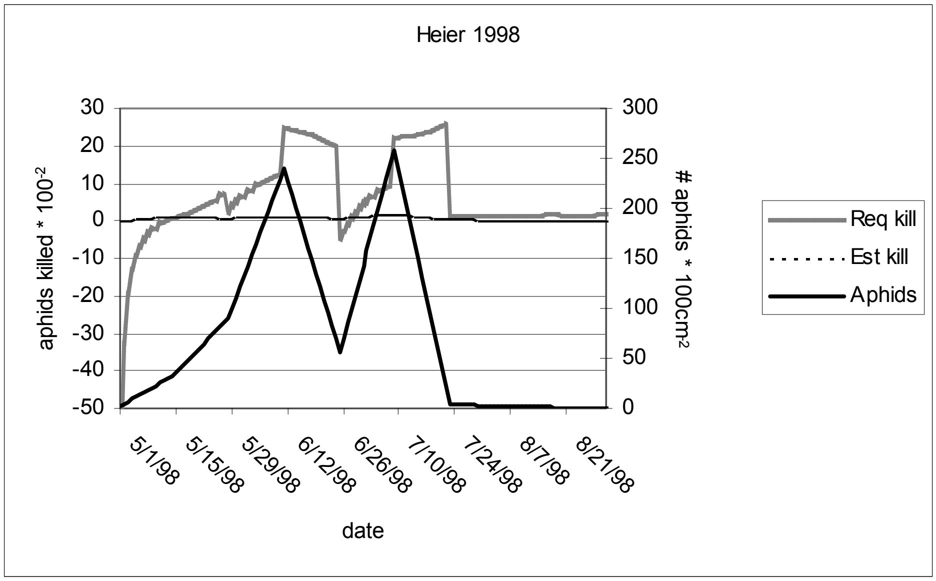


Fig. 5. The relationship between time spent feeding on a single aphid prey and the weight ratio of predator and prey for the major predators of mealy plum aphids in prune orchards.

(a)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aphids * 100cm2
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-50
300
250
200
150
100
50
0
5/1/98
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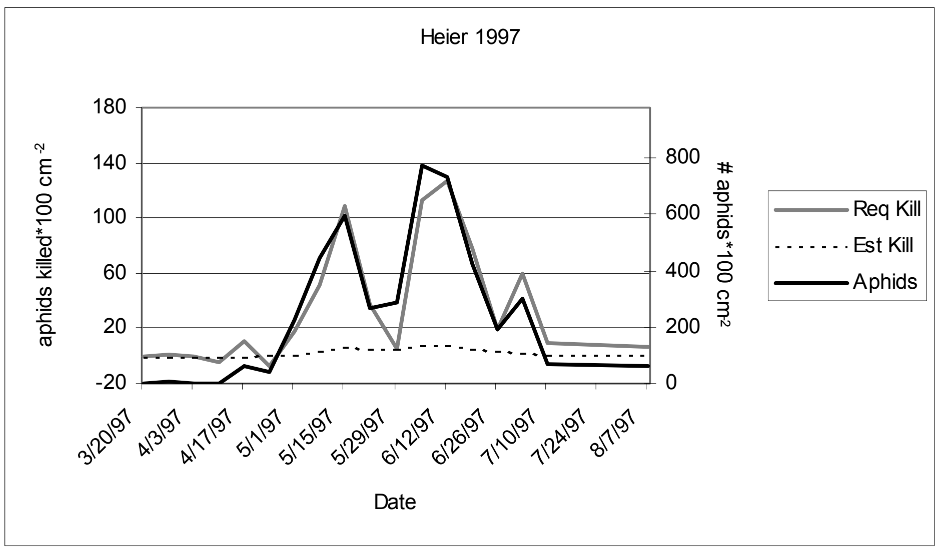
date

(b)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400
200
0
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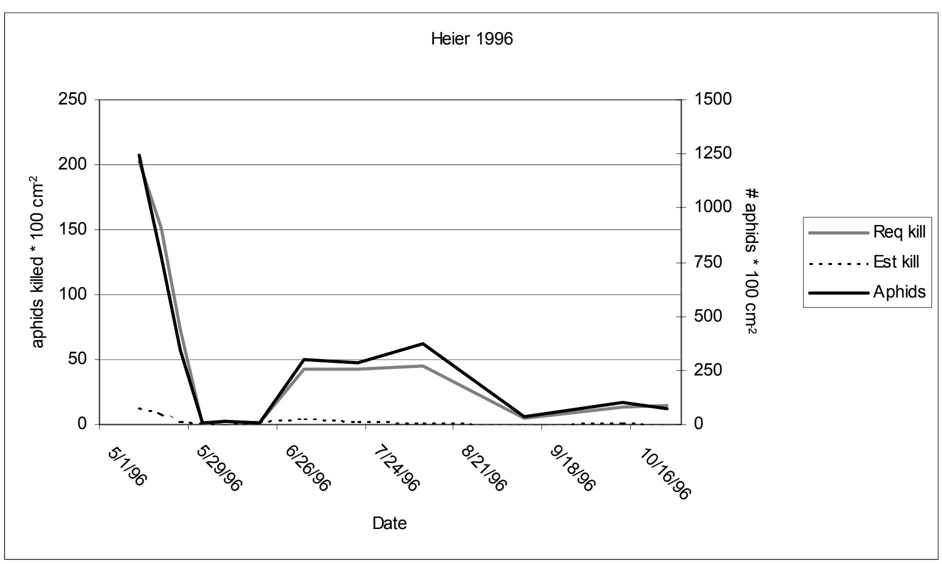
(c)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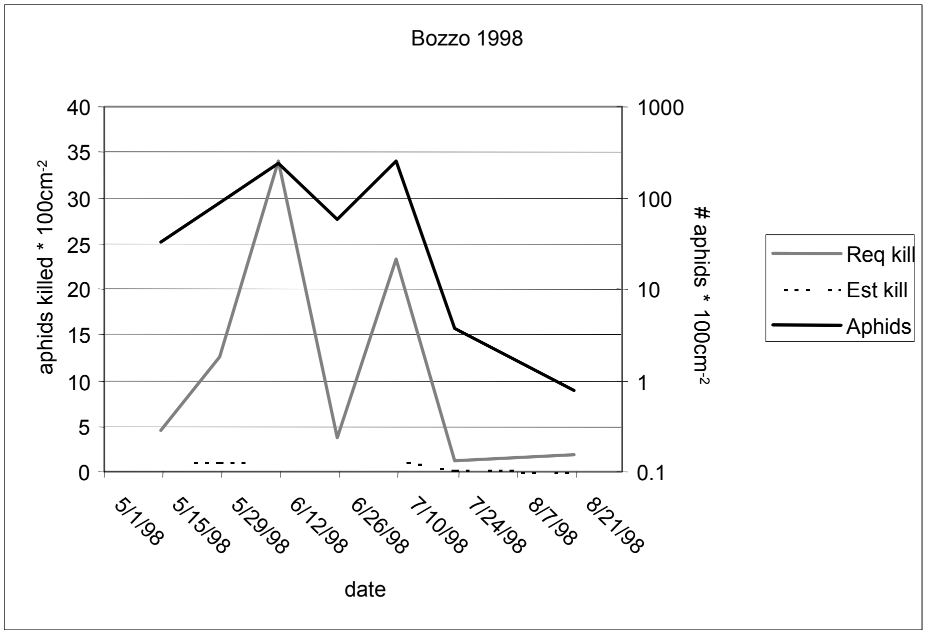
(d)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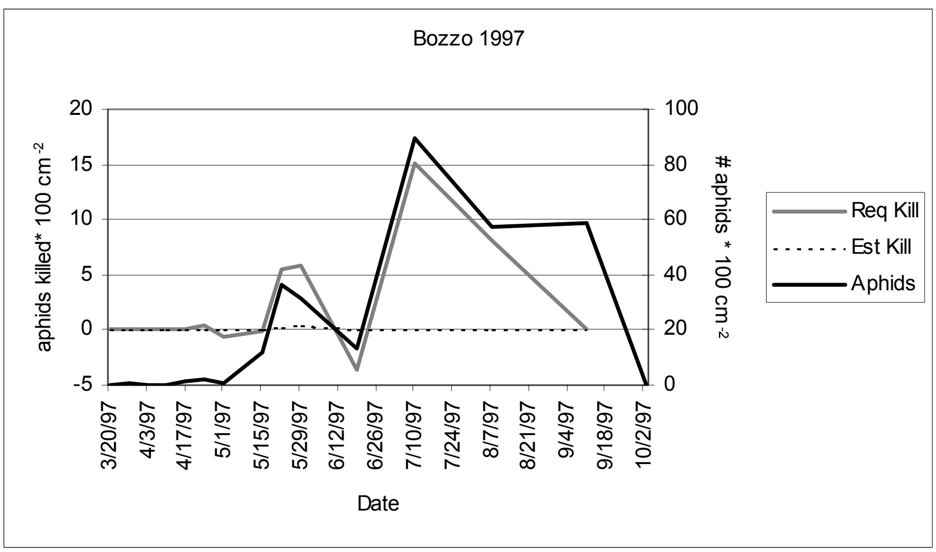
Req kill
Est kill
Aphids

(e)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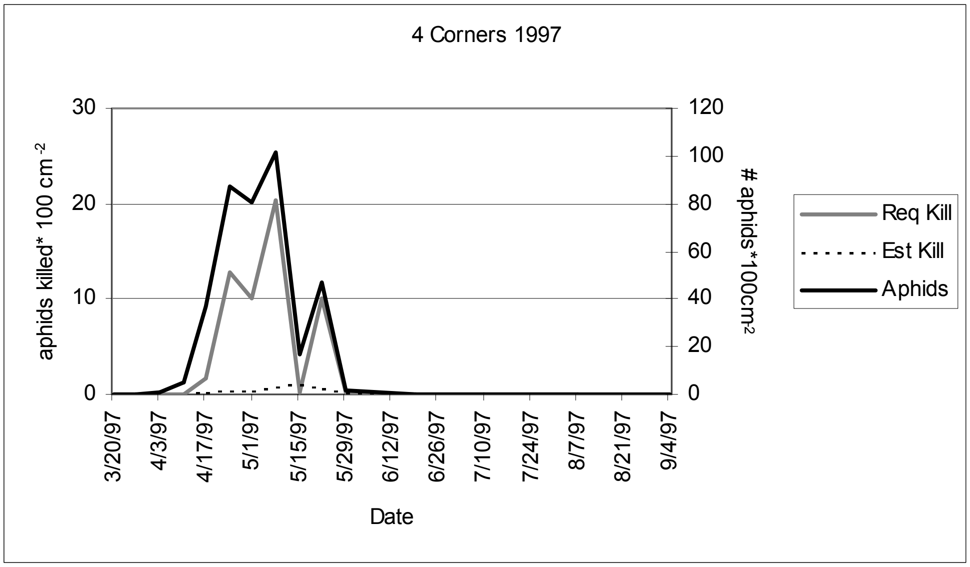
Aphids

(f)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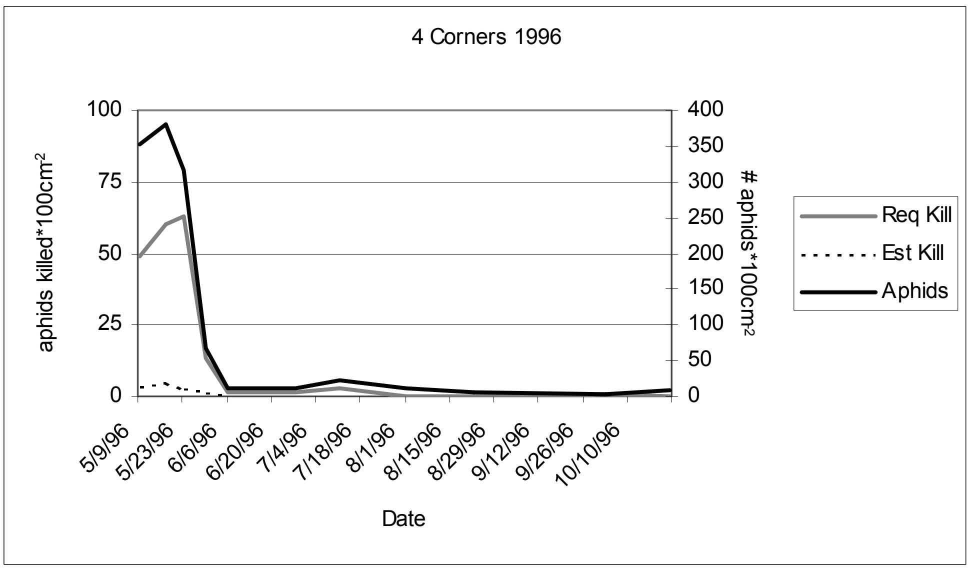
(g)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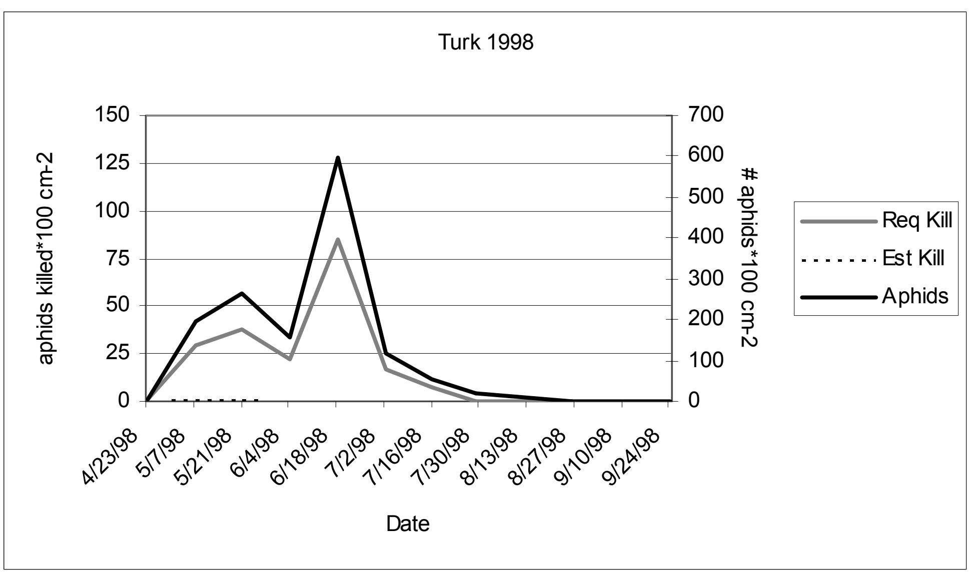
(h)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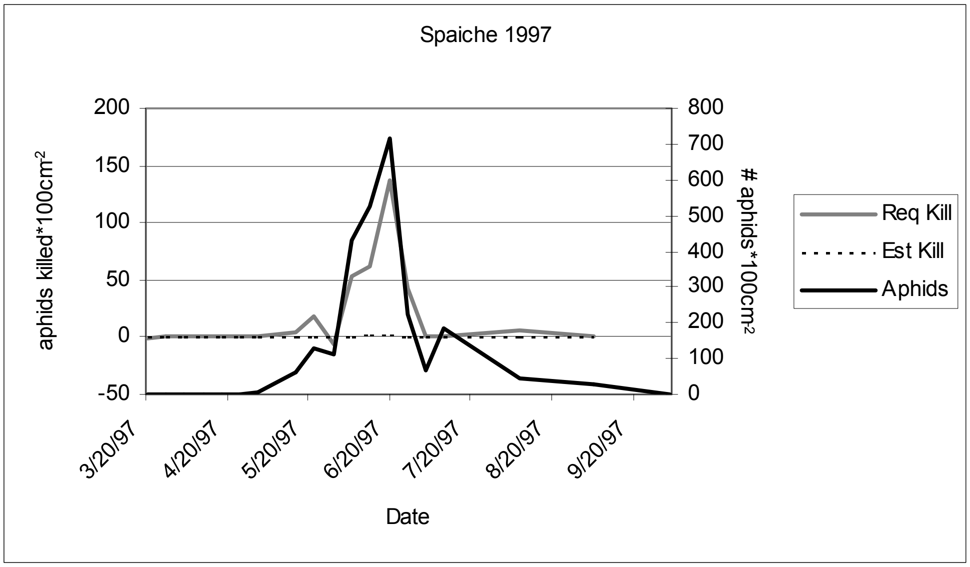
(i)



(j)

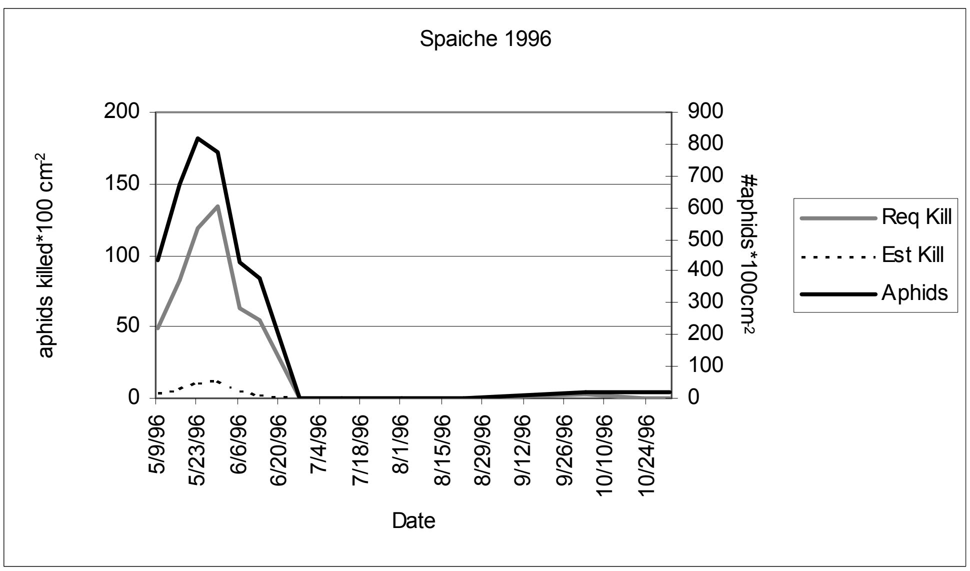
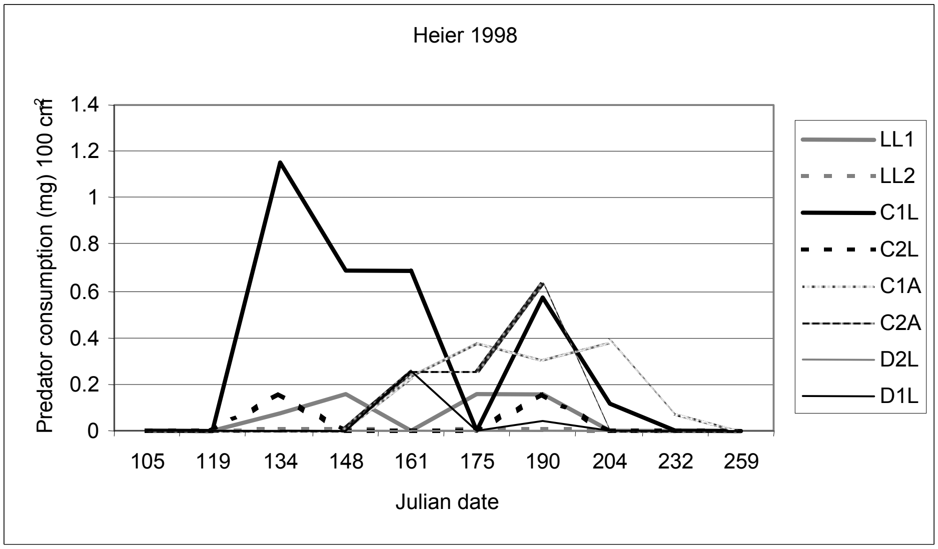
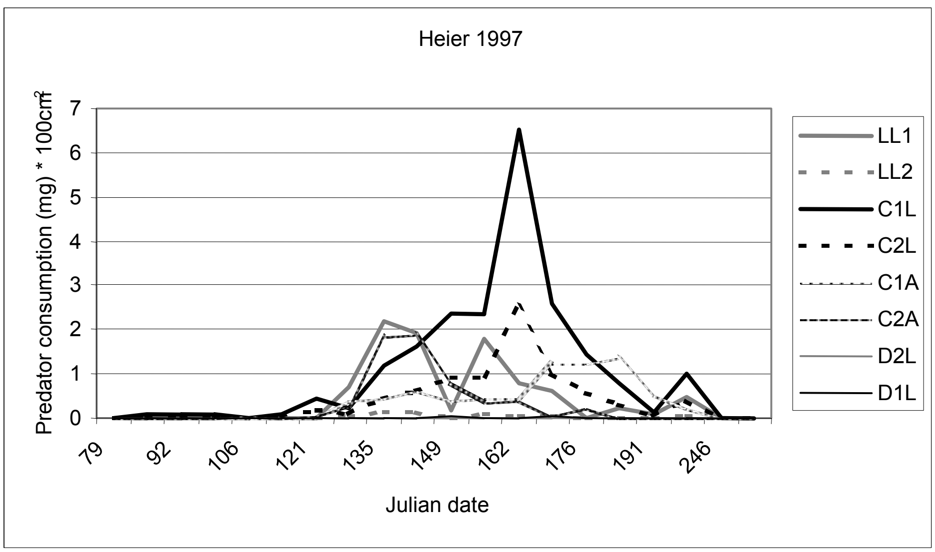


Fig. 6 (a-j) Required kill (predation rate necessary to account for the change in aphid density between sampling dates for a constant instantaneous rate of aphid population increase), estimated kill (predation rate observed in the field by the predator guild) and aphid density through the season for several orchards and years.

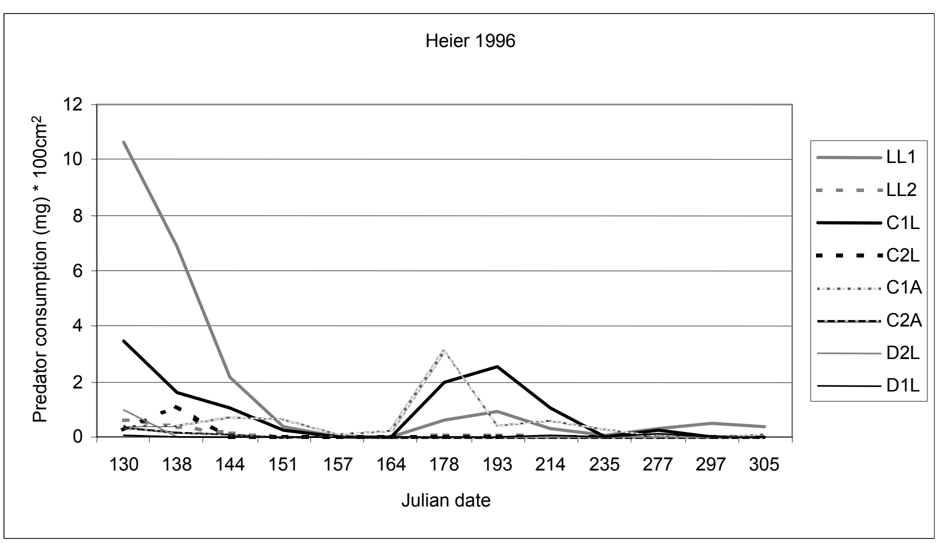
(a)


Heier 1998
Predator consumption (mg) 100 cm2
1.4
1.2
1
0.8
0.6
0.4
0.2
0
105
119
134
148
161
175
190
204
232
259
Julian date
LL1
LL2
C1L
C2L
C1A
C2A
D2L
D1L

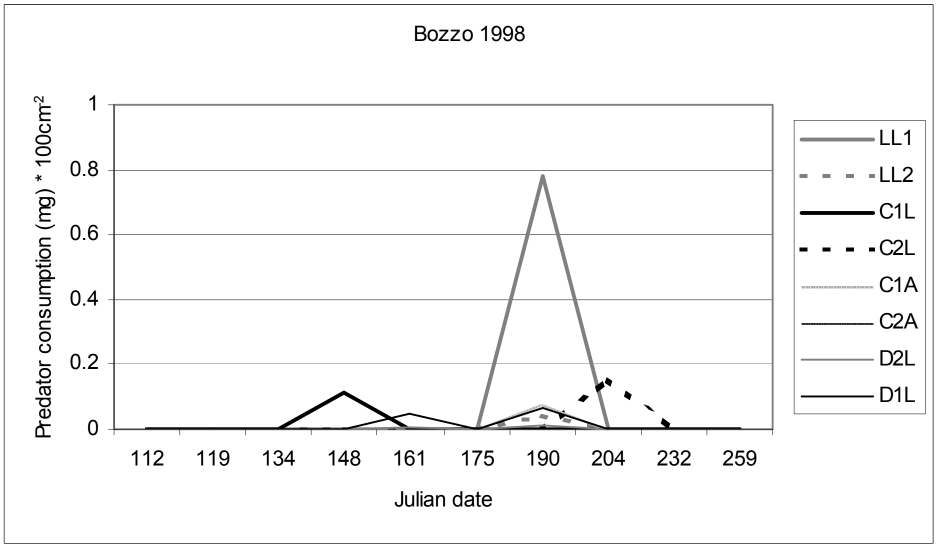
(b)


Heier 1997
Predator consumption (mg) * 100cm2
7
6
5
4
3
2
1
0
79
92
106
121
135
149
162
176
191
246
Julian date
LL1
LL2
C1L
C2L
C1A
C2A
D2L
D1L

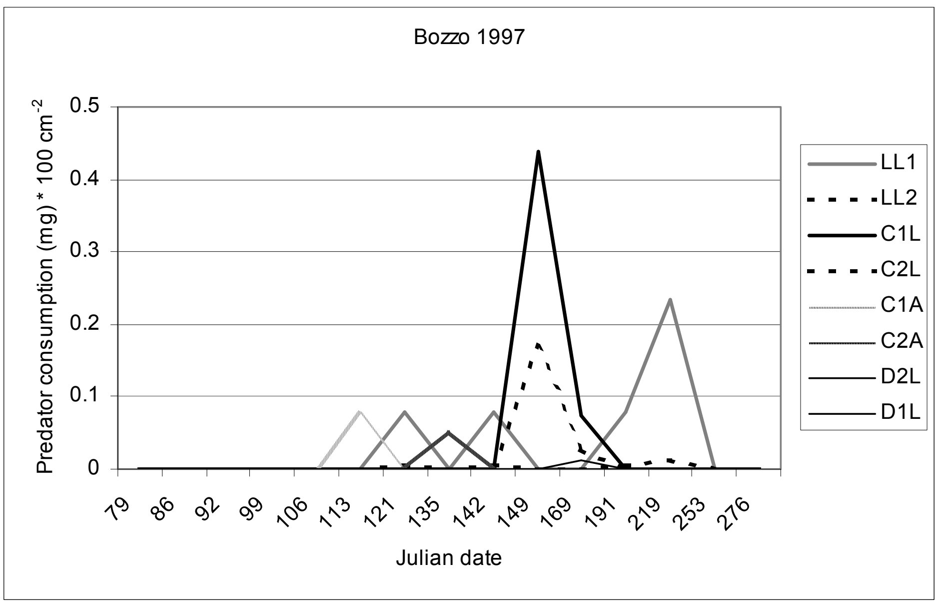
(c)


Heier 1996
Predator consumption (mg) * 100cm2
12
10
8
6
4
2
0
130
138
144
151
157
164
178
193
214
235
277
297
305
Julian date
LL1
LL2
C1L
C2L
C1A
C2A
D2L
D1L

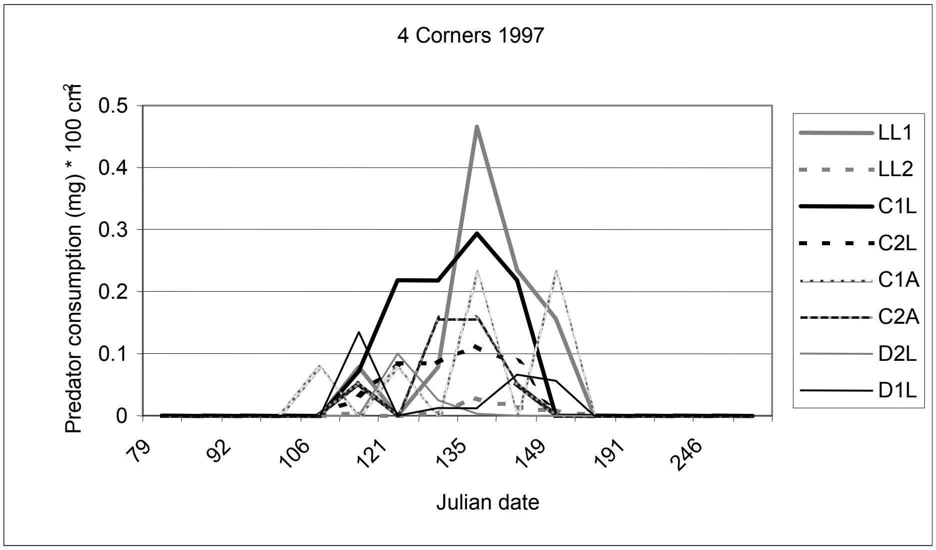
(d)


Bozzo 1998
Predator consumption (mg) * 100cm-2
1
0.8
0.6
0.4
0.2
0
112
119
134
148
161
175
190
204
232
259
Julian date
LL1
LL2
C1L
C2L
C1A
C2A
D2L
D1L

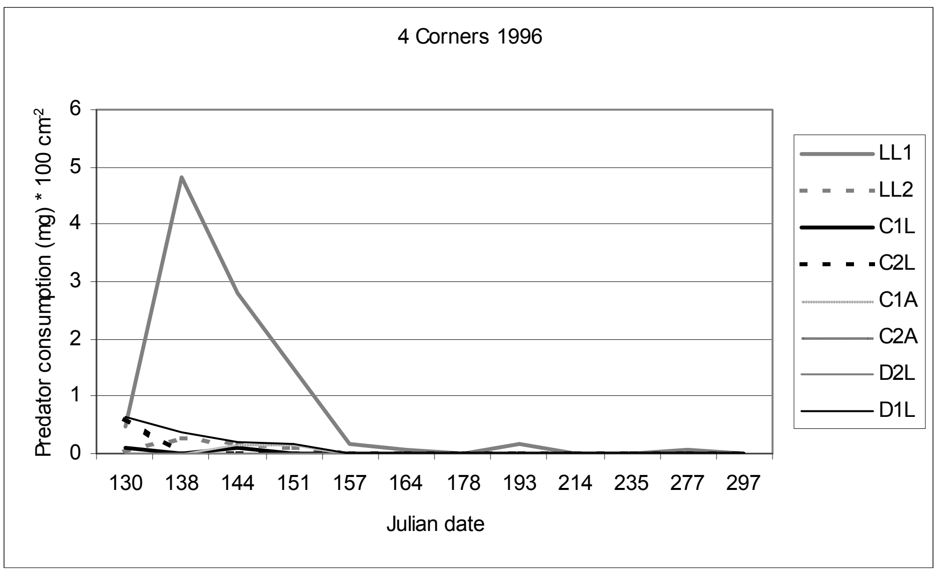
(e)


Bozzo 1997
Predator consumption (mg) * 100 cm-2
0.5
0.4
0.3
0.2
0.1
0
79
86
92
99
106
113
121
135
142
149
169
191
219
253
276
Julian date
LL1
LL2
C1L
C2L
C1A
C2A
D2L
D1L

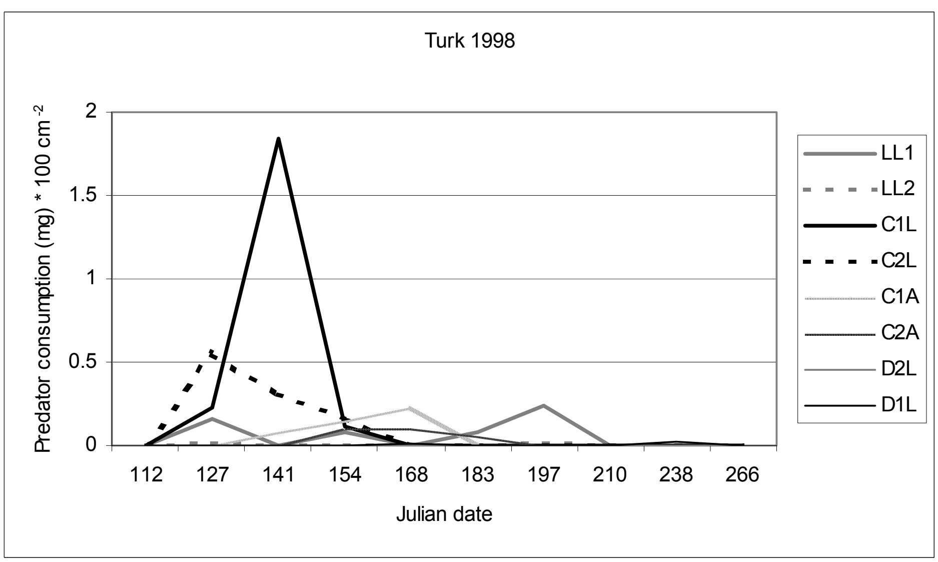
(f)


4 Corners 1997
Predator consumption (mg) * 100 cm-2
0.5
0.4
0.3
0.2
0.1
0
79
92
106
121
135
149
191
246
Julian date
LL1
LL2
C1L
C2L
C1A
C2A
D2L
D1L

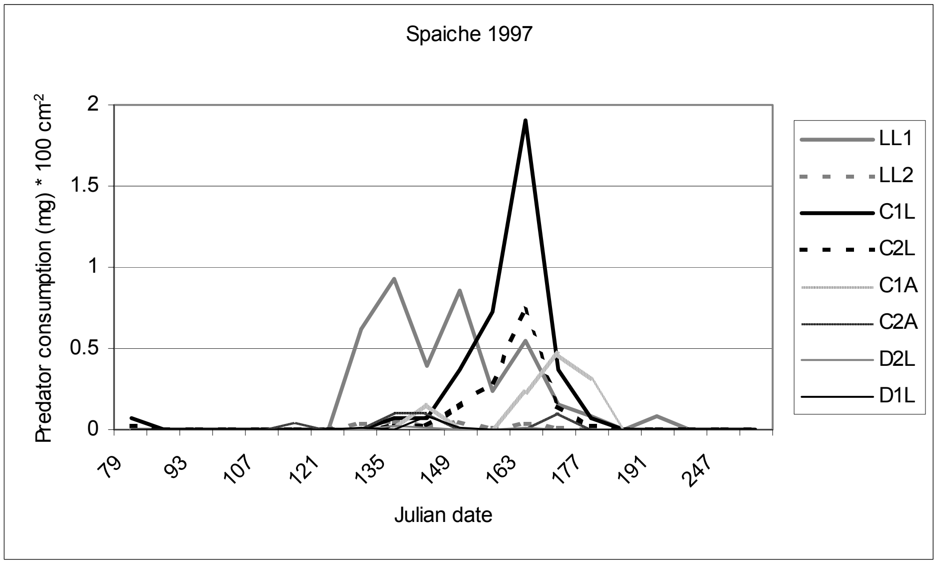
(g)


4 Corners 1996
Predator consumption (mg) * 100 cm-2
6
5
4
3
2
1
0
130
138
144
151
157
164
178
193
214
235
277
297
Julian date
LL1
LL2
C1L
C2L
C1A
C2A
D2L
D1L

(h)


Turk 1998
Predator consumption (mg) * 100 cm -2
2
1.5
1
0.5
0
112
127
141
154
168
183
197
210
238
266
Julian date
LL1
LL2
C1L
C2L
C1A
C2A
D2L
D1L

(i)



(j)

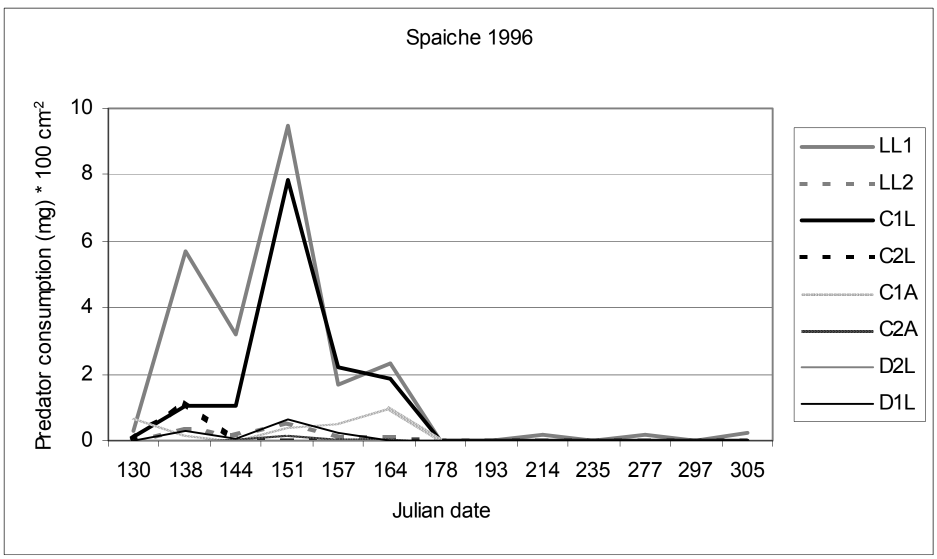


Fig. 7 (a-j) Estimated predation potentials for each predator species for the same series of orchards and years as in Fig. 6. LL1 = *Chrysopa nigricornis* and LL2 = *Chrysoperla carnea* (Chrysopidae); C1L = *Harmonia axyridis* larvae and C2L = *Hippodamia spp.* larvae (Coccinellidae); C1A and C2A coccinellid adults; D1L = *Aphidoletes aphidimyza* (Cecidomyiidae); D2L = *Leucopis* sp. (Chamaemyiidae)